AN AERIAL RADIOLOGICAL SURVEY OF THE JACKPILE-PAGUATE URANIUM MINE AND SURROUNDING AREA

PAGUATE, NEW MEXICO

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ABSTRACT

An aerial radiological survey was conducted over the Jackpile-Paguate Uranium Mine near Paguate, New Mexico, from 27 July to 4 August 1981. The mine is operated by the Anaconda Copper Company on the Laguna Indian Reservation near Grants. The survey was flown at an altitude of 46 m by a helicopter containing 19 sodium iodide detectors. The line spacing was 76 m. Enhanced gamma exposure rate levels were observed at numerous locations in the 98 km^2 survey area. This survey was commissioned by the Geological Survey of the United States Department of the Interior, authorized by the U.S. Department of Energy, and conducted by EG&G, Inc. from its base in Las Vegas, Nevada.

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1.0 INTRODUCTION

The United States Department of Energy (DOE) maintains the Remote Sensing Laboratory (RSL) in Las Vegas, Nevada. This facility is operated for DOE by the Energy Measurements Group of EG&G. Activities at the Laboratory are part of the Aerial Measuring Systems program (AMS). Since its inception in 1958, the AMS program has included radiological surveys of nuclear power plants, processing and manufacturing plants employing nuclear materials, and research laboratories. AMS aircraft have been deployed to nuclear accident sites and in searches for lost radioisotopes, in addition to routine use during launch operations for Apollo, Viking, and other space vehicles which contained radioisotope thermal generators. Most of the AMS equipment and personnel were deployed in the successful search for fragments of Cosmos 954, the Russian nuclear-powered satellite which crashed in the Northwest Territories of Canada in January 1978. AMS aircraft also have mapping cameras and multispectral camera arrays for aerial photography; multispectral scanners for ultraviolet, visible, and infared imagery; a broad array of meteorological sensors; and air sampling systems for particulate and whole gas measurements.

The AMS program is maintained and operated for DOE by EG&G. At the request of federal or state agencies, AMS is deployed for various aerial survey operations. The survey of the Jackpile-Paguate Uranium Mine was commissioned by the Geological Survey of the United States Department of the Interior, authorized by the U.S. Department of Energy, and conducted by EG&G from its Las Vegas base.

In 1953 the Anaconda Copper Company leased land on the Laguna Indian

Reservation from the Pueblo of Laguna. Anaconda has extracted uranium ore from three open pits and eight underground mine operations at Jackpile-Paguate and is currently preparing a Reclamation Plan for the affected land. The objectives of the Anaconda Plan are to reclaim the disturbed area in such a way as to allow the use of the land for grazing, to protect the natural resources of the area, and to meet applicable regulatory requirements of the U.S. Geological Survey.[1]

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2.0 THE SITE

The Jackpile-Paguate Mine is on arid, broken terrain ranging in elevation from 1580 m (5200 feet) to 2040 m (6700 feet). The site is on the Laguna Indian Reservation, approximately 50 km (30 miles) east of Grants, New Mexico. Before mining began the area was similar to present surroundings, which consist of flat-topped, steep-sided mesas, canyons, dry washes and valleys. In the lowest portions of the site were the surface water channels of the Rio Paguate and the Rio Moquino, which converge near the center of the mine area. The combined stream flows 7.2 km (4.5 miles) southeastward to the Paguate Reservoir. Most of the soil in the area consists of medium to coarse textured surface material, moderately to heavily eroded.

Before mining operations began the surface supported sparse grasses and juniper woodland, which provided wildlife habitat. The major pre-mining economic activity was livestock grazing.

In November 1951 the Anaconda Copper Company reached a prospecting and leasing agreement with the Laguna Tribal Council. Elevated nuclear radiation levels were detected in the same month near the Paguate Village in the Jackpile sandstone outcrop. In September 1953, Anaconda began open pit mining operations at the Jackpile deposit. In 1956 the Paguate ore body was discovered about 3 km (2 miles) from the Jackpile discovery. Underground mining began in 1974.

Figure 1 is a drawing of the Jackpile-Paguate area on the Laguna Reservation. The dashed line shows the lease boundary negotiated by Anaconda, which includes approximately 3000 hectares (7500 acres). Since 1953 over 356 million tons of material have been moved in 3 open pits and 8 underground mine operations. Mining activity affects 1075 hectares (2656 acres) of the leased land.

The present aerial survey includes the mined portion of the leased land and drainage areas to the south, including the Paguate Reservoir. Also included is the railroad spur linking the mine areas to the main track of the Atchison, Topeka, and Santa Fe Railroad. The survey boundary, shown as a solid line in Figure 1, encloses 98 km^2 (9800 hectares). It contains the mining operations as well as surrounding areas, which may include ore or mine waste transported from the mines by natural or human processes.

3.0 SURVEY PLAN

The helicopter and mobile computer laboratory used during this survey were based on the survey site. Microwave transponders which provided navigation signals were located to the north and west of the mine on mesas which overlook it.

A total of 133 survey lines were flown at an altitude of 46 m (150 feet), spaced 76 m (250 feet) apart. The northern portion of the survey area was covered by 96 lines, each approximately 12.7 km (7.9 miles) long. Some of these lines were shortened on the west end to avoid flying over Black Mesa. There were no Anaconda operations on Black Mesa and it is unlikely that winds or natural drainage would have carried radioactive materials there.

The southern portion of the survey area was covered by 37 lines, each 3.4 km (2.1 miles) long. These lines covered the Rio Paguate drainage area, including the Paguate Reservoir, and the railroad spur down to its juncture with the Santa Fe line.

Survey coverage was planned with the guidance of the Geological Survey. The objective was to overfly areas where ore and mine waste were purposely exposed and transported, as well as regions where winds, stream drainage, or accidental spillage from railroad cars may have transported radioactive material.

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4.0 SURVEY EQUIPMENT

All survey flights were accomplished between 28 July and 3 August with an MBB BO-105 helicopter, which is shown in Figure 2. The aircraft contained a lightweight version of the Radiation and Environmental Data Acquisition and Recorder (REDAR) system. Two pods, mounted on the left and right helicopter skids, each contained ten 12.7 cm diameter by 5.1 cm thick sodium iodide [NaI(TP)] detectors.

The preamplifier signal from each detector was calibrated with a ^{22}Na source. Calibrated outputs of each detector in the array were combined in a 10-way summing amplifier. Finally, these were combined in a 2-way summing amplifier and fed to an analog-to-digital converter. Calibration peaks were adjusted to appear in preselected channels of the REDAR multichannel analyzer. The data were recorded on 4-track magnetic tape cassettes capable of 54 minutes of storage.

The helicopter position was established with two systems: a Trisponder/202A microwave ranging system and an AL-101 radio altimeter. The Trisponder master station, mounted in the helicopter, interrogated two remote transceivers; these were mounted several kilometers from the survey area. By measuring the round-trip propagation time between the master and remote stations, the master was able to compute the distance to each. These distances were recorded on magnetic tape each second. In subsequent computer processing they were converted to position coordinates.

The radio altimeter aboard the helicopter similarly measured the time lag for the return of a pulsed signal and converted this to aircraft altitude. For these surveys, altitude was accurate to ± 2 m. These data were also recorded on magnetic tape so that any variations in gamma signal strength caused by altitude fluctuation could be accurately compensated.

All data recorded by the REDAR were immediately available to the data technician in the cockpit. Total gamma count rate, gamma spectra, and a variety of housekeeping parameters were displayed on a CRT screen.

Helicopter position data, horizontal as well as vertical, were also fed to a steering indicator computer. Programmed altitude and flight path data were compared with the actual, instantaneous values during each moment of the survey and used to drive a steering indicator with horizontal and vertical position indicators. By centering these the pilot was able to maintain the desired 46 m altitude and 76 m line spacing.

The detectors and electronic systems which accumulate and record the data are described only briefly here. They are described in considerable detail in previous reports.[2,3,4]

Precise coverage of any survey site requires that a parallel array of survey lines be programmed. The altitude must be low and the lines closely spaced so that the probability of detection is high for radiation sources of interest. It is also obvious that programmed survey lines must be accurately flown so that small sources are not lost in accidental gaps between lines. The exact position of the helicopter over the site, and its altitude, are recorded during each second of the survey by the REDAR system.

5.0 DATA PROCESSING EQUIPMENT

Magnetic tapes from these surveys are processed with the Radiation and Environmental Data Analyzer and Computer system (REDAC). This is a computer analysis laboratory built into a 5-ton step van. The interior of the van is shown in Figure 3. The REDAC system consists primarily of two Cipher Data Products tape drives, a Data General NOVA 840 computer, two Calcomp plotters, and a Tektronix CRT display screen with a hard copier. The computer has a 32k-word core memory and an additional 1.2×10^6-word disc memory. An extensive series of software routines is available for data processing.

Gamma spectral windows can be selected for any portion of the spectrum between, for example, 50 keV and 3 MeV. Weighted combinations of such windows can be summed or subtracted and the result plotted as a function of time or position. By the proper selection of windows and weighting factors, it is possible to extract the photopeak count rate for radioisotopes deposited on the terrain by human activity or which have been accumulated by natural processes into radioactive ore bodies. Such depositions disturb the normal pattern of soil radioactivity and can be mapped with some accuracy. A block diagram of the REDAC system is shown in Figure 4.

6.0 DATA ANALYSIS

The specific objectives of the present survey were to produce a gamma gross count map and a bismuth-214 isotope map.

6.1 Gross Count Isopleth Map

To produce a gross count isopleth map the REDAC is programmed to to select gamma counts occurring within a 1-second time interval and from an extremely wide energy interval (50 keV to 3.0 MeV). A conversion factor is applied to the difference between these counts and background of non-terrestrial origin to obtain terrestrial exposure rate at the 1 m level due to sources in the soil. Calibrations are done at 1 m above ground and aerial results are normalized to this elevation because the gonads are the most sensitive portion of human anatomy to external sources of ionizing radiation. The terrestrial and cosmic are summed and plotted as a function of position within the survey site. Their sum represents total external gamma exposure rate, a quantity of biological significance to those living and working in the Jackpile-Paguate area. Figure 5, the gross count isopleth map, is the result of plotting the data in this manner.

Gamma sensitive instruments measure terrestrial plus cosmic radiation. But none, including the RSL sodium iodide detector package, measure both sources with uniform efficiency. The RSL system is nearly linear in response to gamma radiation from 50 keV to 3 MeV. Most of the gammas in this band are of terrestrial origin. The system responds poorly to cosmic radiation, which also occurs both above and below the measured band.

Hence a calibration range has been established near Lake Mead. A ground path has been marked; the exposure rate along the path has been carefully measured at a height of 1 m with calibrated ion chambers and other detectors of high accuracy. The path is overflown with the instrumented helicopter at various altitudes. The helicopter then flies over Lake Mead so that all nonterrestrial background sources, including cosmic rays, can be measured and substracted from the gross gamma count.

Other nonterrestrial sources include minute sources within the materials of which the detectors, electronic systems, aircraft instruments and helicopter are made. Radon gas and other radioactive gases and particulates suspended in the air contribute to flights over both land and water. The cosmic ray contribution usually changes slowly, in response to a variety of environmental conditions; radon and other gas contributions may change within a few hours. It is best to determine background over large water bodies near the survey site, preferably just prior to each flight. Since Jackpile-Paguate is far from such bodies of water, background data from the Lake Mead were used.

No cosmic ray measurements were made at the Jackpile-Paguate site during the aerial survey. Hence an accurate estimate of the cosmic activity must be determined and added to the measured terrestrial activity to determine total external exposure rate. Cosmic ray levels vary, especially as a function of an 11-year solar acitivity cycle. They are also dependent on geomagnetic latitude, pressure, temperature and solar flares. Using ionization rate data for the lower atmosphere, Lowder and Beck[5] calculated average values over the 11-year solar cycle for 50^{0}N geomagnetic latitude. This data was used by Lindeken, et al.,[6] to calculate the cosmic level for many locations throughout the

United States. They corrected for elevation and departures from a geomagnetic latitude of 50^{0}N, obtaining 5.7 μR/h as the exposure rate for Albuquerque.

Since Albuquerque and the Jackpile-Paguate site are at the same geomagnetic latitude (43.8^{0}N), one has to correct for the difference in altitude. At higher elevations, cosmic ray penetration is stronger. Survey terrain varied from 5700 feet near Paguate Reservoir to over 6,700 feet in the foothills of Black Mesa. Inspection of a site map suggests that 6,200 feet is a reasonable average terrain altitude. Calculations by O'Brien suggest that the 900-foot elevation difference between Albuquerque and the Site should add 0.7 μR/h to the calculated exposure rate. Hence, a nominal value of 6.4 μR/h has been assumed for the cosmic ray exposure rate at Jackpile-Paguate.

From data obtained over and near Lake Mead, Nevada, it is known that for the RSL detectors and helicopter the calibration factor (CF) for terrestrial counts are:

$$CF = 1324\ e^{-0.001957\ A_c} = 1055\ \frac{\text{cts/sec}}{\mu\text{R/h}}$$

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where

$$A_c = A_0\ \frac{293}{273+T_0}\ \frac{Po}{14.69}$$

A_0 = the nominal survey altitude (150 feet)

T_0 = the mean site temperature (29.5^{0}C)

P_0 = the mean site barometric pressure (11.73 psi).

Pressure and temperature data obtained from the Albuquerque station of the National Weather Service were normalized to the survey site. Since variations in both air temperature and barometric pressure were quite small during the survey a reasonable approximation for these parameters is their average 1:00pm value between 29 July and 3 August, i.e., 88.3^{0}F and 24.778 in. Hg, respectively. These data were obtained at 5311 feet and normalized to the survey calibration altitude of 6,200 feet. The temperature was decreased by 2^{0}C per 1000 feet, the pressure by 1 in. Hg per 1000 feet to obtain the values shown above.

To compute a conversion table one simply divides the measured count rate over the site by 1055 counts per second to obtain the terrestrial exposure rate. Then 6.4 μR/h is added to each value to obtain total exposure rate, as shown in Table 1.

Table 1. Gamma Gross Count Rate and Exposure Rate at the Jackpile-Paguate Survey

Letter Label	Count Rate (cps)	Total Gamma Exposure Rate at the 1 m Level
A	0 - 3000	0 - 9
B	3000 - 5500	9 - 12
C	5500 - 8000	12 - 14
D	8000 - 12000	14 - 18
E	12000 - 18000	18 - 23
F	18000 - 24000	23 - 29
G	24000 - 35000	29 - 40
H	35000 - 55000	40 - 60
I	55000 - 110000	60 - 110
J	110000 - 200000	110 - 200
K	200000 - 500000	200 - 480

The count rates were averaged over a 3-second sliding interval average before the data were plotted on the gross count isopleth map (Figure 5) An interpretation of its anomalies appears in Section 7.1 of the Results.

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6.2 Bismuth-214 Isopleth Map

The uranium decay chain includes radium-226 and its daughter, radon-222. Radon is a noble gas; hence, it does not combine chemically with other elements. It can diffuse through the soil and move through the air. The amount of radioactivity contributed by radon is dependent upon meteorological conditions, the mineral content and permeability of the soil, and other physical conditions existing at each site at any particular time. Radium-226 and radon-222 are always found with uranium ore and tailings. They produce radiation exposure rates greater than the normal background radiation. Radon alone contributes from 1 to 10 percent of the natural background radiation level at a given location.

Since no milling operations are conducted at the Jackpile-Paguate mine, one can expect that all ore, waste rock, topsoil, etc. within the survey area will be in a natural state. That is, all of the radioactive daughter nuclides will be in secular equilibrium with the parent uranium-238. Hence, the presence of one of these, bismuth-214, can serve as a guide to the level of uranium-238 concentration. Bismuth-214 is selected because it has a characteristic gamma ray photopeak at 1.76 MeV which is 1) prominent in the bismuth-214 spectrum, 2) fairly high in energy and 3) in a portion of the gamma spectrum which is not heavily complicated by many competing gamma peaks.

Hence a computer algorithm has been devised which shows bismuth 214 activity on the ground:

$$^{214}Bi = A - kB,$$

where A = (1580,1928 keV), B = (2360,2864 keV), and

$$1.969 \leq K \leq 2.270.$$

The constant k is empirically determined from background data accumulated during each flight. A is the photopeak window; it cumulates gamma counts between 1580 and 1928 keV. It includes the ^{214}Bi peak at 1760 keV. Sodium iodide spectra have poor spectral resolution, i.e. even though bismuth-214 emits a gamma ray at a discrete energy of 1760 keV, the detector system will count these gammas in a broad band ranging from 10 percent below to 10 percent above the "photopeak energy" of 1760 keV. Hence, window A is deliberately large to capture such evidence of bismuth-214.

Window B accumulates background counts from 2360 to 2864 keV. The window is also broad to accumulate counts statistically comparable to those in window A. Window B, in fact, includes some gammas emitted by bismuth-214; but these have much lower probability than the foreground, i.e., the 1760 keV peak. Bismuth-214 emits gammas at more than 50 discrete energies. Hence it is not possible to pick a background window entirely free of bismuth contributions. The window B chosen above is probably the best available compromise.

The aircraft is flown over regions free of ore piles, known outcroppings of uranium ore, or piles of waste rock. Such "background" regions are arbitrarily defined and only locally valid. The gross count in such regions is average or low. From data obtained over such background regions we compute the ratio K = A/B for each 4-second gamma spectrum. Since this value is highly localized and time-variant, an average value of K is computed for each flight. For Jackpile-Paguate it varied from 1.969 to 2.270.

The constant K computed for a given flight is inserted into the computer algorithm $^{214}Bi = A - kB$. The value of the algorithm is then computed for each gamma spectrum of the flight and plotted on a second-by-second basis at the position where the spectrum was accumulated. For background regions, the algorithm assumes a vanishingly small value. If there are large accumulations of bismuth below the detectors, A becomes large, B remains relatively the same; thus the value of the algorithm fluctuates in direct proportion to the bismuth-214, and hence uranium, concentration in the soil below.

This process is repeated for each flight until the entire survey area has been filled in. Table 2 gives the letter code used to construct the bismuth-214 isopleth contour map, Figure 6.

Table 2. Bismuth-214 Count Rate and Approximate Exposure Rate at Jackpile-Paguate

Letter Label	Count Rate (cts/sec	Approximate Total Gamma Exposure Rate (μR/h)
A	0 - 30	0 - 18
B	30 - 60	18 - 23
C	60 - 120	23 - 29
D	120 - 240	29 - 40
E	240 - 480	40 - 60
F	480 - 960	60 - 110
G	960 - 1920	110 - 200
H	1920 - 3840	200 - 480

Regions characterized by the letter A (0-30 counts/sec) have average or very slightly higher concentrations of bismuth-214. Concentration increases with count rate. The approximate exposure rate shown in column 3 was obtained by comparing count rates in Figure 6 with the total gamma exposure rate at the same location on Figure 5. Detailed soil chemistry studies would be required to determine the exposure rate due only to the bismuth-214 (or any other isotope) in the soil of any given region.

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7.0 RESULTS

The results of the data analysis are presented in Section 7.1 and 7.2

7.1 Gross Count Isopleth Map

In Figure 5, the Jackpile-Paguate gross count isopleth map, the general background within the survey is characterized by the level C (12-14 μR/h). At the C level are Paguate Village, the foothills of Black Mesa, North and South Oak Canyon Mesas, areas north and east of the mine (kncluding Snowbird Mesa), and areas south of the mine. The Rio Paguate drainage basin, and in particualr the Paguate Reservoir, generally show higher exposure rates, viz as high as level F.

There are regions of significant size which show slightly lower B level (9-12 μR/h) activity north of Paguate Village, northeast of the Jackpile Pit, the northeast corner of the survey area, Wiener Mesa, parts of North and South Oak Canyon Mesa, the area surrounding Snowbird Mesa, and large portions of the southern part of the survey area.

The sodium iodide detectors measure primarily the surface of the soil. Few gamma rays are energetic enough to penetrate more than 10-20 centimeters of soil. Hence the B level areas above could conceal subsurface deposits of higher acitivity. Only soil sampling techniques can reveal the presence of such deposits. For the same reason, the aerial data may show higher than normal acitivity which, upon sampling proves to be only a shallow surface deposit.

The sensitivity of the gamma detectors to radiation from uranium and its daughters is a complex problem. For point radiation sources, on the soil surface, one can easily calculate the stength of the smallest source which can be detected under given survey conditions. But uranium ore is a distributed source, of variable strength horizontally and vertically. The ore may be covered with alluvial material of variable depth and very low activity.

It is quite probable that an acre of F-level material would be detected if surrounded by C-level material-terrestrial counts from the former are 3 times that of the latter. But the size of the F-level contour could be smaller than the ore body or larger: smaller if there is overburden of low activity, larger if the ore deposit is primarily on the surface.

Hence, without a series of complex calculations covering a range of ore distributions, one connot present a valid answer to the question of system sensitivity. These calculations must then be compared to typical Jackpile-Paguate soil profiles and distribution patterns. Lacking these data the author cannot validly estimate the minimum quantity of ore which may have been discovered in this Survey.

There are two anomalously low A (0-9 μR/h) regions behind the Paguate Reservoir dam. The soil in the reservoir region is probably not accurately characterized in the present survey because at least some portions of the region were covered with water. Flight lines in the south portion were obtained one or two days after a heavy rainstorm. Very moist soil and and soil covered with variable water depths will show anomalously lower exposure rates because the water attenuates gamma ray penetration. The two A regions within the reservoir would probably show higher activity if surveyed in dry condition. It is also

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possible that the F levels (23-29 μR/h) behind the center of the dam would be higher. From the present data one cannot estimate how much higher the exposure rate might be.

In general, one may expect that, for soil not covered by water, the exposure rates measured during this survey are accurate to $\pm 20\%$. For example, the aerial results near the reservoir correlate quite well with data recently obtained by the Eberline Instrument Corporation.[8] Most of the data shown on their Plate 1 (dated December 1980) agrees with the present aerial results to within $\pm 20\%$. There are, however, two glaring exceptions -- hotspots found by Eberline 6500 feet north-northwest of the center of the dam. The first, at New Mexico State coordinates W651100 and N1487300, shows exposure rates as high as 37 μR/h; the second, at W651100 and N1486900, goes to 47 μR/h. The aerial results show no hotspots, only D level activity (14-18 μR/h) in that area. It is possible that these hotspots were removed prior to the aerial survey, or severely attenuated by water, soil or some other intervening medium. If neither is the case, the hotspots were averaged with surrounding background. The detectors collect gamma signals from a circle of large diameter on the ground; the diameter varies directly with the energy of the gamma rays. This tends to smear hotspots of small size. In addition, the data are subjected to a 3-second sliding interval average, which also forces them to blend with surrounding background. The above speculations can be resolved only by measurements at the site, by taking soil samples or using portable gamma sensitive instruments.

One can summarize the radiation data gathered over Jackpile-Paguate by preparing a count rate frequency distribution, as shown in Figure 7. For the gross count isopleth map, Figure 5, counts obtained each second were averaged with a 3-second, sliding interval average. This tends to minimize statistical fluctuations. Each of these averaged points were plotted in Figure 5 (along with a calculated cosmic ray contribution.)

To prepare Figure 7, the frequency of occurrence was determined for terrestrial count rates in background regions. Every other background data point in Figure 5 was considered, i.e., from each survey flight line the first, third, fifth, etc, count rate was included in the frequency distribution. And areas known to be rich in uranium, including ore stockpiles and pits, were excluded from consideration, i.e., no count rates were considered inside the dotted line in Figure 5 marked "Background Boundary."

The abscissa in Figure 7 is the number of counts per second from terrestrial sources in background areas surrounding the Jackpile-Paguate mine. The ordinate is the number of times this count rate occurred. The most probable modal terrestrial count rate is 6475 counts/second, equivalent to 6.1 μR/h; this rate occurred 2662 times. A dashed vertical line shows the most probable count rate.

The distribution is quite obviously skewed to higher count rates which indicates this region has more than a "normal" number of sub-regions of higher activity. Of course, one expects this in proximity to uranium-rich soil. A normal (symmetrical) distribution would imply that the bismuth-214, and hence uranium, was homogeneously distributed in the soil. If one adds the calculated 6.4 μR/h cosmic data to the modal terrestrial value, one notes that level C, 12-14 μR/h is the most probable total exposure rate for the background. The mean terrestrial count rate is 7363 counts/sec, which is equivalent to a terrestrial exposure rate of 7.0 μR/h, a total exposure rate of 13.4 μR/h. Since the C level (12-14 μR/h) is quite broad, it accommodates both measures of the distribution.

The author has not conducted soil chemistry studies at the Jackpile-Paguate site, nor has he been able to obtain sufficiently comprehensive data from Anaconda or any other source. Such data, showing the composition of various radionuclides in site soil, would be extremely useful. One could easily compute the exposure rate due to each radionuclide.

It is known that the thorium-232 series and potassium-40 each contribute an average of 2 to 3.3 μ R/h and the uranium series contributes 1.3 to 1.6 μR/h for typical soil.[9] Fragmentary data obtained by the U.S. Environmental Protection Agency[10] at sites near the Jackpile-Paguate mine showed a 24-sample potassium-40 activity of 21.5 *pCi/g*. This would produce an average exposure rate of 3.8 μR/h.

Figure 7 was prepared by choosing a background area, i.e. an area with low levels of uranium and thorium. Hence from the above we can assume the background makes exposure rate contributions shown in Table 3.

Table 3. Assumed Exposure Rate Contributions for Jackpile-Paguate Background

Radiation Source	Exposure Rate(μR/h)	Percentage Contribution
potassium-40	3.8	28.1%
Thorium series	2.0	14.8%
uranium series	1.3	9.6%
cosmic radiation	6.4	47.4
Total	13.5	

Note the sum of the terrestrial contributions nearly equals the mean terrestrial exposure rate of 7 μR/h computed from Figure 7. This suggests the assumptions in Table 3 are valid. However, detailed soil chemistry studies are required for verification.

Within the mining district soil samples will obviously show high level contributions to the total exposure rate. These will vary, depending on their proximity to ore bodies. In the same EPA data cited above[10], radium-226 activity near the Jackpile housing area is exceptionally high. For example, two homesites show 4.7 *pCi/g;* hence its daughters ^{214}Pb and ^{214}Bi can be expected to contribute 0.94 μR/h and 7.5 μR/h, respectively, to total exposure rate if they are in equilibrium with ^{226}Ra. For typical soil ^{226}Ra averages approximately 1 *pCi/g* and its daughters contribute correspondingly less.

For the gross count isopleth map (Figure 5), contours have been drawn in various colors for emphasis. Since the most probable exposure rate outside the Background Boundary is level C (12-14 μR/h), levels A, B, C, and D, are shown in black. These levels are considered to be natural background for the Jackpile-Paguate area.

Blue color emphasizes the mining district, i.e. levels E and higher which show evidence of mining activity on the aerial photograph and various geological maps. Green color highlights E and higher level activity outside the mining district. Finally, white is used for F and Higher level exposure rates within the mining which apparently have not been mined. Comments regarding all of these anomolous (colored) regions are shown in Table 4 below. Numbers 20 through 43 shown in Figure 5, were arbitrarily assigned for easy reference.

Table 4. High Exposure Rate Regions at Jackpile-Paguate

AREA NUMBER	EXPOSURE RATE (μR/h)	COMMENT
20 to 26	18 to 29	These areas in the Quirk Reservoir probably represent fine particles of ore washed into the Rio Paguate and the Rio Moquino from ore piles and exposed deposits. Because of the dam they have accumulated over the years in the reservoir. D level activity stretching north, nearly to the mining district, confirms this observation.
27 to 28	18 to 29	Small, localized areas along the railroad right-of-way suggest the ore was spilled from cars during transportation to the mill. The ability of the aerial detector system to locate such spills has been confirmed in recent surveys.
29 to 30	18 to 23	Natural deposits of ore; no apparent mining or exploratory activity at these sites.
31 to 34	23 to 60	It appears this area has not been mined, but surface soil has been removed to construct a maintenance facility and road. Subsurface soil shows activity much higher than background.
35	40 to 110	Surface soil has been removed to construct maintenance facilities. The subsurface is considerably higher than local background
36	23 to 110	Surface soil has been disturbed; however, it does not appear that extensive mining activity has taken place at this location.
37	23 to 60	Surface soil has been disturbed; an unimproved road leads to the area. It appears as though exploratory development has taken place here.
38 and 39	18 to 23	Natural deposits. The photographic base map shows that no extensive exploratory work has been done in these locations. The mining district. There are very many areas within the district which show mining activity. Because the soil has been so extensively disturbed over a long time period, little relevant commentary can be made here.
41	18 to 23	Primitive roads and a small structure in the area. No extensive mining development.
42	18 to 23	Primitive roads in the area. The site may have been sampled but there is no extensive mining development.
43	18 to 23	No apparent development in this area

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As previously indicated, aerial survey data are primarily an index of surface activity, i.e., the top 10-20 cm of soil. Uranium concentrations can be calculated only if the deposit is homogeneous or if the depth distribution is known. It may be of interest to calculate concentrations and estimate the uranium content of areas 20 through 39 and 41 through 43 in Table 4. Appropriate soil sampling could establish the variation in concentration with depth. Since this information is unknown to the author, such calculations are beyond the scope of the present report.

One can determine the relative acitivity levels of various dumps, stockpiles, waste materials and borrow pits by examining the exposure rates for these areas. The Anaconda Reclamation Plan, Plate 4. 1-2, was used as a base map for Figure 8. The same gross count data used in Figure 5 are used in Figure 8; the Anaconda basemap facilitates our discussion of exposure rates within the mining district.

The labels and, hence, exposure rates of Table 5 associated with each area appear to be the most appropriate characterization for the whole area. In many cases a unique exposure rate can only be assigned with some difficulty, for several reasons:

1. Some of the areas have ambiguous identifications, perhaps because boundary lines have been omitted from Plate 4.1-2 or because more than one label has been assigned to a given area.
2. Some of the areas are quite large, possibly of heterogeneous origins and not alike in their radioactivity (either in strength or isotopic composition)

3. The spatial resolution of the detector system is insufficient to separate adjacent areas of substantially different gamma activity.

The last difficulty is well illustrated by topsoil dump TS-2A, which has been assigned the label D (14-18 μR/h) in Table 1. Well over half of the dump appears to be at considerably higher levels; the southeast tip of the dump terminates in level K (200-480 μR/h), the highest exposure rate on the map. Close imspection of the photographic base map shows that the dump is on top of a finger of land protruding into the North Paguate Pit. The topsoil is above the original grade at the edge of the pit. The very high activity is within the pit, in the pit wall, or at the very tip of the topsoil dump. Its high level of activity effectively obscures the background exposure rate of TS-2A.

At a survey altitude of 46 m the detectors may "see" high level activity as far as 400-500 m from the helicopter. This range is dependent upon several variables: survey altitude, source intensity, gamma spectrum conposition, air density, relative humidity, source azimuth (relative to the helicopter), and source shielding. If the gamma spectrum is rich in high energy gamma rays the source can be seen at a much greater distance because high energy gammas penetrate the soil, intervening air and the detector housing more readily than low energy gammas. High level sources are more easily seen at either side of the helicopter than from the front or rear because of the far greater surface area on the side of the array. The soil itself may shield an ore or tailings pile non-uniformly. For example, ore buried in the north wall of the NOrth Paguate Pit could perhaps be detected easily when the helicopter is within the pit, but not seen at all when it is above the lip or north of the pit. Under such circumstances the distribution and intensity of the source, as measured by the aerial system, may be distorted.

For some areas within the lease boundary a unique characterization is straightforward. Such areas are marked with an asterisk in Table 5. For the remaining areas the radiation label is less certain because of the small size of the area or its proximity to areas of very different exposure rate or the poor identification provided on the base map.

7.2 Bismuth-214 Isopleth Map

The bismuth contour shown map, shown as Figure 6, is statistically less reliable than the gross count contour map because it selects one relatively small contribution to the total gamma spectrum. Nevertheless, it provides valuable information, viz, it identifies the uranium chain contribution to the soil.

A careful comparison between the gross count and bismuth contours shows that peaks in gross count are always accompanied by peaks in bismuth concentration. The level D on the gross count map corresponds roughly (in shape, size and position) to A on the bismuth map, E to B, etc. For the largest peaks, K corresponds to H. Hence, one can correlate the letter lables on the bismuth map with total gamma exposure rates, as shown in Table 2. It must be emphasized that no attempt has been made to determine the exposure rate due to bismuth alone. But the close correspondence between maps suggests that activity above background can be strongly correlated with radioactive constituents of the uranium chain. Acitivity due to potassium, elements of the thorium chain, and other radioactive constituents of the soil would have to be separately investigated. Neither of the isopleth maps produced for this report yielded information about specific radionuclides other than bismuth.

Table 5: Exposure Rate Summary

Area		Classification	Label	Exposure Rate (mr/hr)
North Paguate Pit	-northwest	Planned backfill	I	60-110
	-southwest	"	I	60-110
	-south	"	H	40-60
	-southeast	"	H	40-60
	-north central	"	K	200-480
	-northeast	"	H	40-60
	-center	"	H	40-60
South Paguate Pit	-northwest	Planned backfill	H	40-60
	-west	"	D	14-18
	-south	"	G	29-40
	-center	"	H	40-60
	-southeast	Existing backfill	E	18-23
	-northeast		I	60-110
Jackpile Pit	-north	Planned backfill	I	60-110
	-east	Existing backfill	J	110-200
	-south	"	H	40-60
	-west	Planned backfill	G	29-40
4-2*		Stockpiles to be milled	J	110-200
Q		"	J	110-200
SP-1*		"	I	60-110
2-E*		"	J	110-200
2-C*		"	J	"
2-D*		"	J	"
10*		"	J	"
J-2*		"	J	"
17-BC*		"	K	200-480
6-B*		"	J	110-200
17-D*		"	I	60-110
6-A*		"	J	110-200
4-1*		Waste material to backfill	I	60-110
1-A*		"	I	"
1-C		"	J	110-200
1-B		"	I	60-110
J-1*		"	I	"

Area	Classification	Label	Exposure Rate (mr/hr)
J	Dump to backfill	F	23-29
TS-3*	Topsoil dumps	C	12-14
TS-2A	"	D	14-18
TS-2B	"	D	"
TS-1*	"	B	9-12
FD-2*	Dump areas to be modified	C	12-14
SP-2*	"	I	60-110
FD-3	"	D	14-18
P*		E	18-23
O*		D	14-18
P_1		C	12-14
P_2*		D	14-18
S		C	12-14
T		D	14-18
U		I	60-110
N		I	"
N_2*		J	110-200
R		G	29-40
L		D	14-18
K		C	12-14
V		G	29-40
W		I	60-110
B		D	14-18
Y		E	18-23
Y_2		D	14-18
I		E	18-23
X		E	18-23
H*		I	60-110
G*		D	14-18
F		D	14-18
E*		D	"
D		D	"
C		D	"
FD-1		D	"

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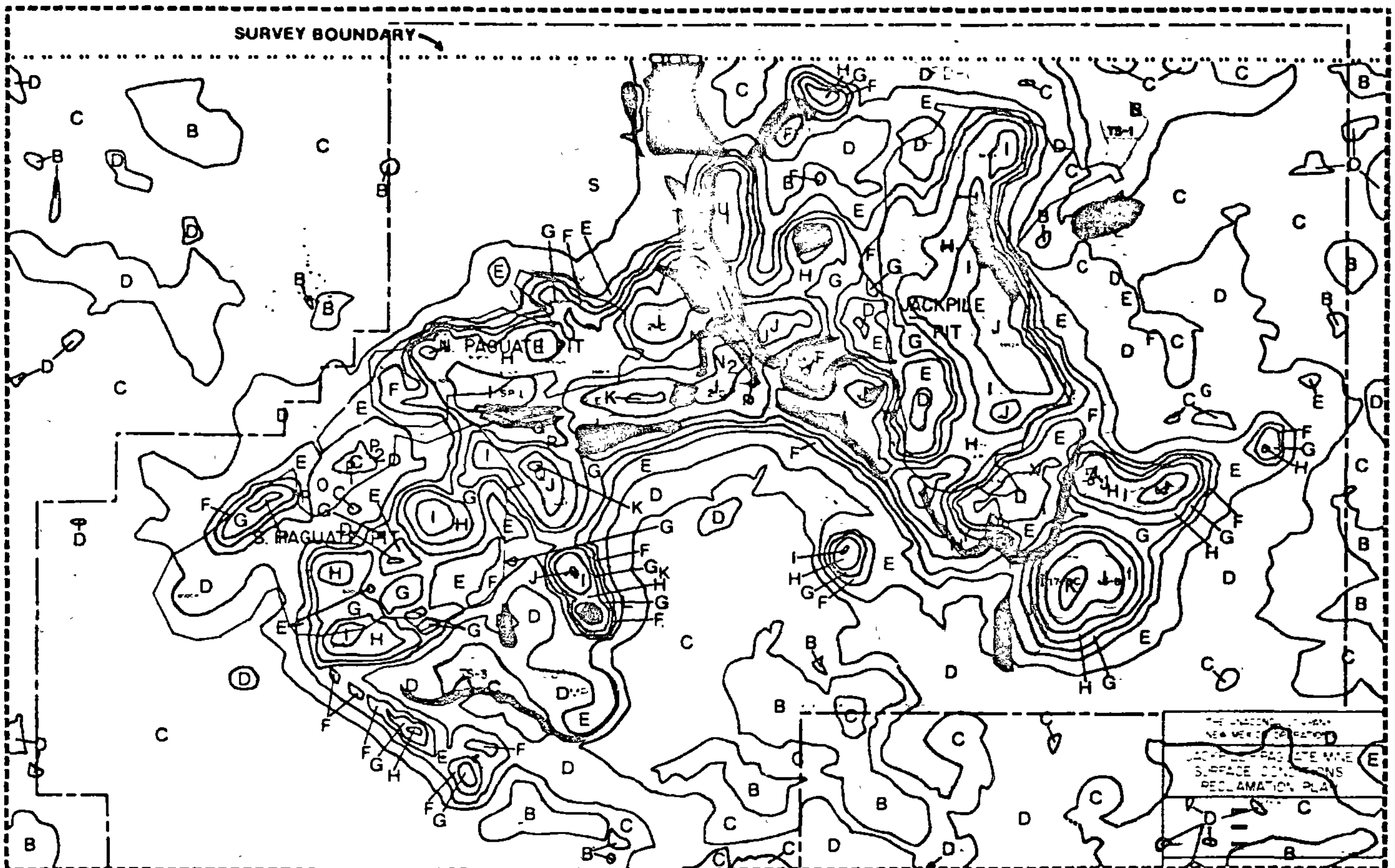


* This isopleth shows gamma ray exposure rates at 1 meter above ground due to terrestrial sources in the energy range $0.050 \leq E_\gamma \leq 3.000$ MeV. Each level also includes a 6.4 μR/h cosmic ray contribution to the exposure rate. The survey altitude was 46 meters. The base map is Plate 4.1-2. Anaconda Reclamation Plan, Vol. 2, 1980.

CONVERSION SCALE*

A	0 - 9
B	9 - 12
C	12 - 14
D	14 - 18
E	18 - 23
F	23 - 29
G	29 - 40
H	40 - 60
I	60 - 110
J	110 - 200
K	200 - 480

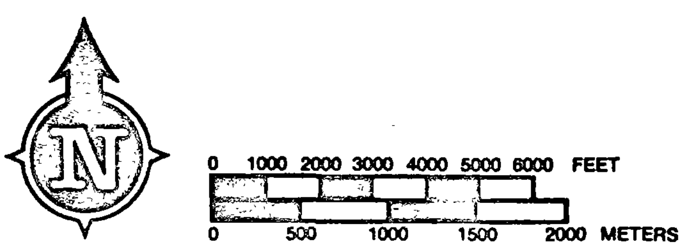
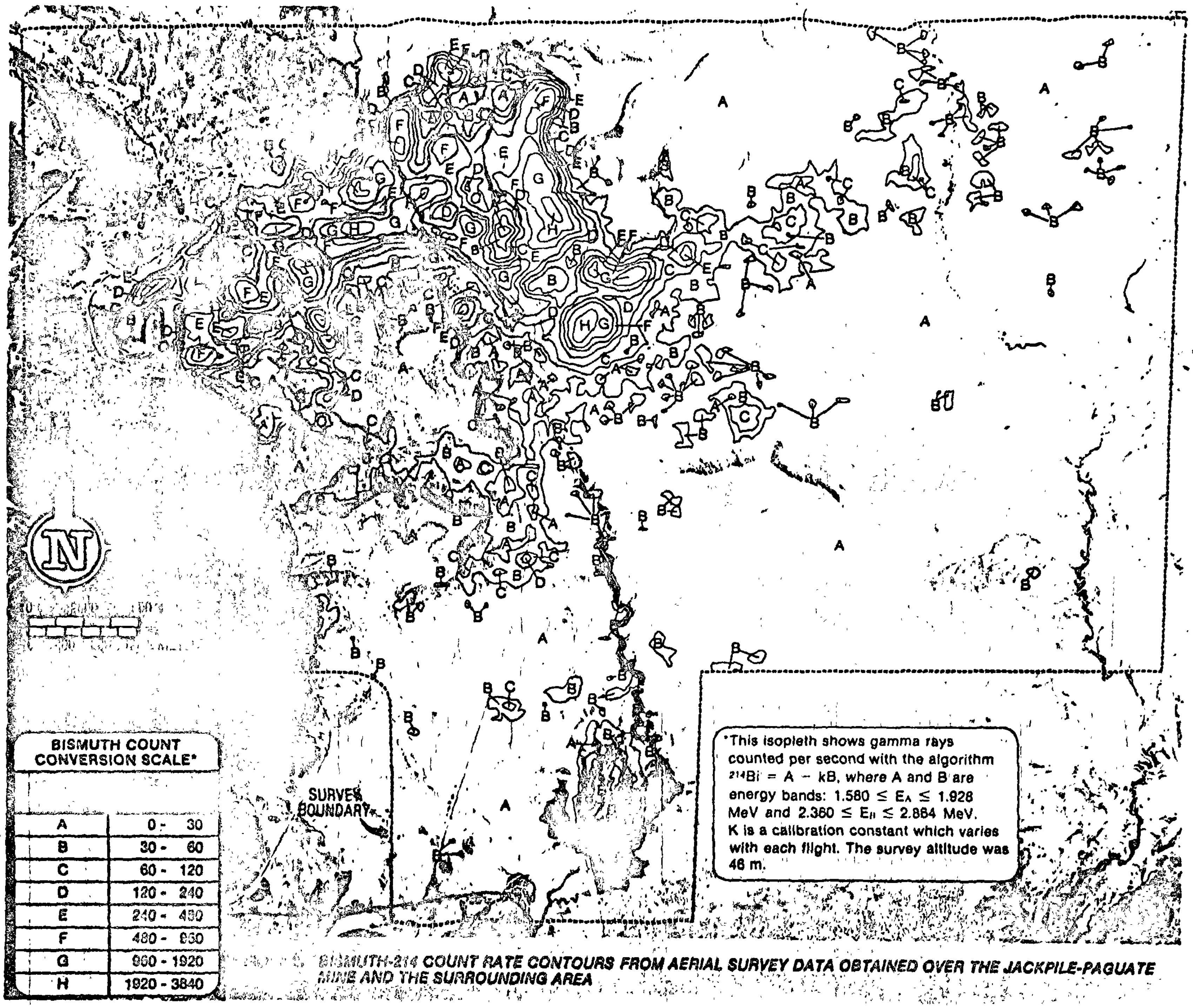
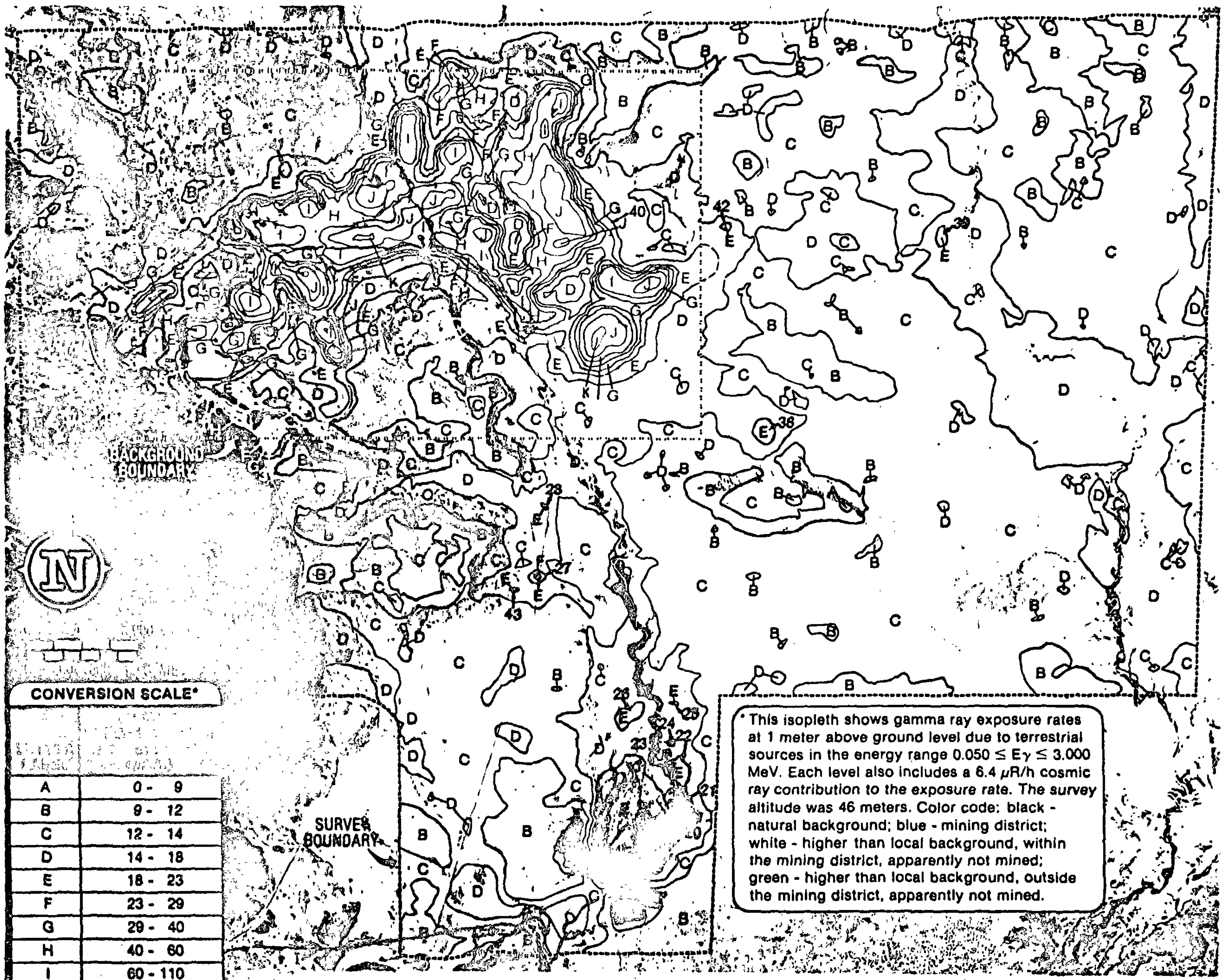


FIGURE 6. TOTAL GAMMA RAY EXPOSURE RATE CONTOURS FROM AERIAL SURVEY DATA, SUPER[illegible] JACKPILE-PAGUATE MINE



BISMUTH-214 COUNT RATE CONTOURS FROM AERIAL SURVEY DATA OBTAINED OVER THE JACKPILE-PAGUATE MINE AND THE SURROUNDING AREA



CONVERSION SCALE*

A	0 - 9
B	9 - 12
C	12 - 14
D	14 - 18
E	18 - 23
F	23 - 29
G	29 - 40
H	40 - 60
I	60 - 110
J	110 - 200
K	200 - 480

* This isopleth shows gamma ray exposure rates at 1 meter above ground level due to terrestrial sources in the energy range 0.050 ≤ $E\gamma$ ≤ 3.000 MeV. Each level also includes a 6.4 μR/h cosmic ray contribution to the exposure rate. The survey altitude was 46 meters. Color code: black - natural background; blue - mining district; white - higher than local background, within the mining district, apparently not mined; green - higher than local background, outside the mining district, apparently not mined.

Figure 5. ***TOTAL GAMMA RAY EXPOSURE RATE CONTOURS FROM AERIAL SURVEY DATA OBTAINED OVER THE JACKPILE-PAGUATE MINE AND THE SURROUNDING AREA***